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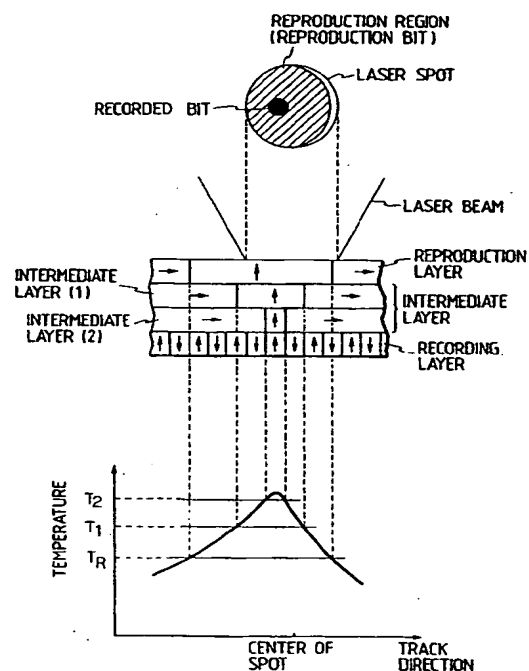
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(54) **Magneto-optical recording medium and method for reproducing information therein.**

(57) A magneto-optical recording medium includes a first magnetic layer and a second magnetic layer. The first magnetic layer is a horizontal magnetization layer at room temperature but a perpendicular magnetization layer at a raised temperature. A transition temperature of the first layer continuously or stepwise increases from a light incidence side thereof light in a film thickness direction. The second magnetic layer is a perpendicular magnetization layer both at room temperature and at the raised temperature. In reproduction of information, an optical beam is applied onto the magneto-optical recording medium in which information is recorded by directions of magnetization. The information recorded in the second magnetic layer is transferred to the first magnetic layer and the information is read by the magneto-optical effect.

FIG. 2



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BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a magneto-optical recording medium for recording or reproducing information therein with a laser beam by utilizing the magneto-optical effect. More particularly, the present invention relates to a magneto-optical recording medium which can increase the density of information recorded in the medium and a method for reproducing information therein.

Related Background Art

As a rewritable high-density recording method, attention has been directed to a magneto-optical recording medium in which magnetic domains are written on a magnetic thin layer by thermal energy of a semiconductor laser to record information, and from which the information is read using the magneto-optical effect.

A recent demand is high to increase a recording density of the magneto-optical recording medium so as to provide a larger storage recording medium.

A linear recording density of an optical disc such as the magneto-optical recording medium is determined mainly by an S/N ratio of a reproduction layer, which depends considerably on a bit string cycle of signal, a laser wavelength of a reproduction optical system and a numerical aperture of an objective lens.

Namely, once a laser wavelength λ of a reproduction optical system and a numerical aperture NA of objective lens are determined, a bit cycle f as being a detection limit is also determined to be $\lambda/2NA$.

On the other hand, a track density of optical disc is restricted mainly by cross talk. The cross talk depends mainly on a distribution (profile) of laser beam on a surface of the medium and is represented by a same function of $\lambda/2NA$ as the above-mentioned bit cycle is.

Accordingly, in order to increase the density of information to be recorded with a conventional optical disc, the laser wavelength of reproduction optical system needs to be shortened and the numerical aperture NA of objective lens needs to be enlarged.

However, there are limitations as to an improvement in the laser wavelength and an improvement in the numerical aperture of objective lens. Therefore, such techniques have been developed that a structure of recording medium or a reading method is improved so as to increase the recording density.

For example, Japanese Laid-open Patent Application No. 3-93058 attempted to improve the recording density by using a medium having a reproduction layer and a recording layer. Namely, magnetization in the reproduction layer is aligned with one direction before reproducing information, and then the informa-

tion held in the recording layer is transferred to the reproduction layer so as to decrease inter-symbol interference upon reproduction, whereby information with a cycle less than the diffraction limit of light can be reproduced.

However, Japanese Laid-open Patent Application No. 3-93058 has such a drawback that an adequate reproduction power cannot be obtained. In more detail, each bit in the recording layer is transferred to the reproduction layer and reproduced therefrom in the same size as it is recorded. Since the each bit is recorded in the recording layer in the size considerably smaller than the size of laser spot, the resolving power will be very low with such small bits.

Further, since the magnetization in the reproduction layer must be aligned with one direction before irradiation of laser beam, an initialization magnet for the reproduction layer needs to be added to conventional apparatus. Therefore, the above-mentioned reproduction method has such problems that the magneto-optical recording apparatus is complicated, the cost is high and miniaturization is hardly possible.

SUMMARY OF THE INVENTION

The present invention has been accomplished to solve the above problems. An object of the present invention is to provide a magneto-optical recording medium and a method for reproducing information therein, by which sufficient resolving power can be obtained in reproducing information, by which information with a cycle less than the diffraction limit of light can be reproduced, and which enable to reduce the size of apparatus.

The above object can be attained by a magneto-optical recording medium comprising a first magnetic layer which is an in-plane (horizontal) magnetization layer at a room temperature but a perpendicular magnetization layer at a raised temperature, and a transition temperature of which increases continuously or stepwise from an incidence side of light in a film thickness direction, and a second magnetic layer which is a perpendicular magnetization layer.

Further, the above object can also be achieved by a method for reproducing information in a magneto-optical recording medium comprising a first magnetic layer which is a horizontal magnetization layer at room temperature but a perpendicular magnetization layer at a raised temperature, and a transition temperature of which continuously or stepwise increases from an incidence side of light in a film thickness direction, and a second magnetic layer which is a perpendicular magnetization layer, wherein the information recorded in the second recording layer is transferred to the first magnetic layer, whereby the information is read by the magneto-optical effect.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1A and 1B are drawings to show the schematic principle of reproduction of a magneto-optical recording medium of the present invention; Fig. 2 is a drawing to show the details of a method for reproducing information in the magneto-optical recording medium;

Figs. 3A and 3B are drawings to show the details of a method for reproducing information in the magneto-optical recording medium;

Figs. 4A, 4B and 4C are drawings to show a relation among saturation magnetization, perpendicular magnetization anisotropy and temperature of each layer in case of a first magnetic layer comprising a reproduction layer and two intermediate layers;

Fig. 5 is a drawing to show C/N ratios of magneto-optical recording media of the present invention;

Figs. 6A and 6B are schematic drawings to show a film structure of the present invention; and

Fig. 7 is a drawing to show a state in which information is recorded in a magneto-optical recording medium of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Magneto-optical recording media and a method for reproducing information therein according to the present invention will be described below in detail with reference to the accompanying drawings.

A magneto-optical recording medium of the present invention comprises at least a first magnetic layer composed of layered films, which is a horizontal magnetization layer at room temperature but a perpendicular magnetization layer at a raised temperature, and a transition temperature (a temperature at which the horizontal magnetization layer changes into the perpendicular magnetization layer) of which increases continuously or stepwise from an incidence side of light in a film thickness direction, and a second magnetic layer which is a perpendicular magnetization layer both at room temperature and at the raised temperature.

Structure and Composition of the Medium

The first magnetic layer is desirably made for example of a rare earth-iron group amorphous alloy such as GdCo, GdFeCo, GdTbFeCo, GdDyFeCo or NdGdFeCo. Preferably, a material for the first magnetic layer has weak magnetic anisotropy and a compensation temperature existing between the room temperature and a Curie temperature of the material.

The second magnetic layer is desirably made for example of a material having strong perpendicular magnetic anisotropy to maintain a magnetization

state stably. For example, a rare earth-iron group amorphous alloy such as TbFeCo, DyFeCo or TbDyFeCo, garnet, platinum group-iron group periodic films such as Pt/Co or Pd/Co, or a platinum group-iron group alloy such as PtCo or PdCo is desired.

Further, in order to improve the corrosion resistance, an element such as Cr, Al, Ti, Pt or Nb may be added to the magnetic layers.

Further, in order to enhance the interference effect, a dielectric layer made of SiN_x, AlN_x, AlO_x, TaO_x or SiO_x may be formed adjacent to either of the above magnetic layers.

Furthermore, in order to improve the thermal conductivity, a layer of Al, AlTa, AlTi, AlCr or Cu may be formed.

Yet furthermore, an intermediate layer to control an exchange coupling force or a magneto-static coupling force, or an assisting layer for recording assist or reproduction assist may be provided. In addition, a dielectric layer as described above or a protective coat of a polymer resin may be added as a protective layer.

Next described are a method for recording information in a magneto-optical recording medium of the present invention and a method for reproducing the information recorded.

(In the following description, described is a case where the first magnetic layer is composed of three films having respective transition temperatures different from one another (referred to as a reproduction layer, an intermediate layer 1 and an intermediate layer 2 from the incident side of light) and the second magnetic layer (referred to as a recording layer) is laminated directly on the first magnetic layer.)

As shown in Fig. 7, information is first recorded in the recording layer in the magneto-optical recording medium of the present invention. Recording is conducted by irradiating a laser beam with power which can raise the temperature of the recording layer at least up to a Curie temperature thereof and modulating an external magnetic field, or, by once erasing all information and thereafter modulating laser power while applying a magnetic field in a recording direction to a recording area. Instead, the recording may be conducted by modulating the laser power while applying an external magnetic field to a recording area. In the recording, if an intensity of laser beam is so determined that only a selected region within a laser spot comes to have the temperature near the Curie point of the recording layer, taking the linear velocity of the recording medium into consideration, magnetic recording domains smaller than the laser spot diameter can be formed. As a result, information can be recorded with a cycle less than the diffraction limit of light.

The medium is irradiated with a reproduction laser beam in reproducing information. With irradiation an irradiated spot increases its temperature. Since

the medium moves at a constant speed, a temperature distribution on the medium has a shape extended in the moving direction of medium, in which only a portion within the laser spot becomes high in temperature, as shown in Fig. 2.

Incidentally, it is known about a single layer of magnetic thin film that the main direction of magnetization is determined by an effective perpendicular magnetic anisotropy constant K_L which is defined by the following formula:

$$K_L = K_u - 2\pi M_s^2$$

where M_s is a saturation magnetization and K_u is a perpendicular magnetic anisotropy constant. If K_L is positive, the layer is a perpendicular magnetization layer. On the other hand, if it is negative, the layer is a horizontal magnetization layer.

Here, $2\pi M_s^2$ is demagnetizing energy. If the layers are formed in the relations among the temperature, the saturation magnetization M_s , and the perpendicular magnetic anisotropy constant K_u as shown in Figs. 4A, 4B, 4C,

$$K_u < 2\pi M_s^2 \text{ and then } K_L < 0,$$

at room temperature (RT). Thus, the layers each are kept as a horizontal magnetization layer at RT. On the other hand, the temperature is raised during reproduction, and M_s of each magnetic layer in the first magnetic layer becomes smaller. As a result, $2\pi M_s^2$ becomes rapidly smaller, whereby the above relation to the perpendicular magnetic anisotropy constant K_u becomes inverted. Namely,

$$K_u > 2\pi M_s^2 \text{ and then } K_L > 0$$

at the raised temperature. Then, the layers each can be changed into a perpendicular magnetization layer as the temperature increases.

Namely, if the saturation magnetization M_s and the perpendicular magnetic anisotropy constant K_u of each of the reproduction layer, the intermediate layer 1 and the intermediate layer 2 are so set, taking an intensity and a linear velocity of laser beam during reproduction into consideration, that each of the reproduction layer, the intermediate layer 1 and the intermediate layer 2 becomes perpendicularly magnetized in accordance with the temperature distribution within the laser spot as shown in Fig. 2, only a portion of each layer is perpendicularly magnetized in a desired temperature region within the laser spot, while other portions remain as a horizontal magnetization layer. Further, when the reproduction layer, the intermediate layer 1 and the intermediate layer 2 are perpendicularly magnetized, they are magnetically coupled with adjacent layers by exchange coupling. As a result, the magnetization in the reproduction layer, the intermediate layer 1 or the intermediate layer 2 is stably aligned with the magnetization direction based on information in an adjacent layer. In other words, the information recorded in the recording layer is transferred to the reproduction layer. Then, the information thus transferred is converted into an optical

signal by the magneto-optical effect of the reproduction layer (more particularly, by the magneto-optical effect of the laser beam reflected on the reproduction layer) and the thus converted signal is detected. In this case, there is no magneto-optical effect appearing in the horizontal magnetization portions in the reproduction layer within the laser spot.

In case a perpendicular magnetization layer is laminated directly or via an intermediate layer on the first magnetic layer, a temperature region for perpendicular magnetization is shifted to a lower temperature side as compared with a non-laminated case. This is because K_u becomes apparently increased by the exchange coupling force from the magneto-static coupling force of the perpendicular magnetization layer. However, if the perpendicular magnetization temperature region of the single layer before laminated is set to be slightly higher, it is possible to establish such a condition that the first layer is a horizontal magnetization layer at room temperature but a perpendicular magnetization layer at a raised temperature, after the perpendicular magnetization layer is laminated on the first layer.

Here, the reproduction layer, the intermediate layer 1 and the intermediate layer 2 in the first magnetic layer have mutually different transition temperatures at each of which each layer changes from a horizontal magnetization layer to a perpendicular magnetization layer (i.e., magnetization direction transition temperatures) and the magnetization direction transition temperatures are set to increase in the order of the reproduction layer, the intermediate layer 1 and the intermediate layer 2 (the intermediate layer 2 has the highest transition temperature). Hereinafter, the transition temperatures of the reproduction layer, intermediate layer 1 and intermediate layer 2 are represented by T_R , T_1 and T_2 , respectively, and the medium temperature is represented by T .

As set as described above, a part of each of reproduction layer, the intermediate layer 1 and the intermediate layer 2 becomes perpendicularly magnetized within the laser spot during reproduction (Fig. 2), and the perpendicular magnetization portions therein become larger in the order of the intermediate layer 2, the intermediate layer 1 and the reproduction layer.

In more detail, a portion (the temperature $T \geq T_2$ region) of magnetization in the intermediate layer 2 adjacent to the recording layer becomes perpendicularly magnetized during reproduction to be exchange-coupled with the recording layer, and the magnetization of that portion becomes aligned with a stable direction relative to the magnetization direction based on information recorded in the recording layer. At the same time, a portion of magnetization in the intermediate layer 1 (the temperature $T \geq T_1$ region that is wider than the temperature $T \geq T_2$ region) also becomes perpendicularly magnetized to be exchange-coupled with the intermediate layer 2, and the mag-

netization of that portion is aligned with a stable direction relative to the magnetization direction in the perpendicular magnetization portion of the intermediate layer 1. Furthermore, a portion of the reproduction layer (the temperature $T \geq T_R$ region that is wider than the temperature $T \geq T_2$ region) becomes simultaneously perpendicularly magnetized to be exchange-coupled with the intermediate layer 1, and the magnetization of that portion is aligned with a stable direction relative to the magnetization direction in the perpendicular magnetization portion of the intermediate layer 1. As a result, a bit in the recording layer is transferred to the reproduction layer in an enlarged scale.

As described above, a micro bit formed in the recording layer is transferred in an enlarged scale to the reproduction layer which contributes most to the C/N ratio in reproduction. Accordingly, the C/N ratio is remarkably improved as compared with the conventional magnetic super resolution.

Further, the method for reproducing information according to the present invention, can permit reproduction of a bit without being affected by adjacent bits in the track direction and in the radial direction, whereby both the linear recording density and the track density can be improved to realize a great improvement in the recording density.

The above description concerned a case where the first magnetic layer was composed of three layers (reproduction layer and two intermediate layers) having different transition temperatures from each other. In another case, the first magnetic layer may be composed of a reproduction layer having a certain transition temperature and an intermediate layer laminated thereon the transition temperature of which is continuously changed (Figs. 3A and 3B). Or, the first magnetic layer may be composed of a single composition-graded layer the composition of which is continuously changed (Figs. 1A and 1B).

Further, the above description showed a case where the magnetic layers were magnetically coupled with each other by the exchange interaction. In a modification, the layers may be magnetically coupled with each other by the magneto-static coupling.

Furthermore, in order to make the transfer clearer, an intermediate layer different in Curie temperature may be formed between the magnetic layers.

The present invention will be described in more detail referring to experimental examples, but it should be understood that the present invention is not limited to the specific examples, but involves all embodiments constructed without departing from the scope of the invention.

Example 1

Targets of Si, Tb, Gd, Fe and Co were set in a direct current (DC) magnetron sputtering system and a polycarbonate substrate 1 was fixed in a substrate

holder. Then, the chamber was evacuated to high vacuum of at most 1×10^{-5} Pa by means of cryopump.

While evacuating to vacuum, Ar gas was introduced into the chamber up to 0.3 Pa. Then, a SiN layer 2 (dielectric layer) as an interference layer 2 was formed in thickness of 700 Å; a GdFeCo layer 3 as a reproduction layer 3 was then formed in thickness of 400 Å; a GdFeCo layer 4 as a first intermediate layer 4 was next formed in thickness of 50 Å; a GdFeCo layer 5 as a second intermediate layer 5 was formed in thickness of 50 Å; a TbFeCo layer 6 as a recording layer 6 was formed in thickness of 300 Å; and a SiN layer 7 (dielectric layer) as a protective layer 7 was finally formed in thickness of 700 Å in the named order to obtain a magneto-optical recording medium of a layered film structure (as shown in Fig. 6A).

During the formation of the SiN layers, N_2 gas was introduced in addition to Ar gas and the film formation was conducted by DC reactive sputtering. The GdFeCo layer and the TbFeCo layer were formed by applying DC power to each target of Gd, Fe, Co and Tb.

The composition of the GdFeCo reproduction layer was so set that the compensation temperature was 150 °C and the Curie temperature was at least 350 °C.

The composition of the first GdFeCo intermediate layer was so set that the compensation temperature was 220 °C and the Curie temperature was at least 350 °C.

The composition of the second GdFeCo intermediate layer was so set that the compensation temperature was 280 °C and the Curie temperature was at least 350 °C.

The composition of the TbFeCo recording layer was so set that the layer was TM-rich at room temperature and that the Curie temperature was 200 °C.

Then, recording and reproduction characteristics were measured using the magneto-optical recording medium thus obtained.

The measuring apparatus had NA of objective lens and a laser wavelength being 0.55 and 780 nm, respectively. Recording power was from 8 to 10 mW, and linear velocity was 9 m/s (rotational speed: 2400 rpm, radius: 36 mm). A carrier signal of from 5.8 to 18 MHz was written in the recording layer by the magnetic modulation method to evaluate recording frequency dependency of the C/N ratio. Applied field was ± 150 Oe.

Reproduction power was so set that the C/N ratio became maximum.

The results thus obtained are shown in Fig. 5.

Example 2

Thin layers were formed on a polycarbonate substrate 1 by the same film-forming machine and method as in Example 1 to obtain a magneto-optical re-

ording medium, which was evaluated under the same conditions as in Example 1.

A SiN layer 2 (dielectric layer) as an interference layer 2 was formed in thickness of 820 Å; a GdFeCo layer 3 as a reproduction layer 3 was formed in thickness of 400 Å; a GdFeCo layer 4 as a composition-graded intermediate layer 4 was formed in thickness of 100 Å; a TbFeCo layer 5 as a recording layer 5 was formed in thickness of 400 Å; and a SiN layer 6 (dielectric layer) as a protective layer 6 was formed in thickness of 700 Å in the named order to obtain a magneto-optical recording medium of a laminated film structure (as shown in Fig. 6B).

The composition of the GdFeCo reproduction layer was so set that the compensation temperature was 280 °C and the Curie temperature was at least 350 °C.

The composition of the GdFeCo composition-graded intermediate layer was so set that the compensation temperature and the Curie temperature were 170 °C and at least 350 °C, respectively, on the side adjacent to the reproduction layer and the compensation temperature and the Curie temperature were 290 °C and at least 350 °C, respectively, on the side adjacent to the recording layer, and that the compensation temperature was continuously changed in the film thickness direction.

The composition of the TbFeCo recording layer was so set that the layer was TM-rich at room temperature, and the Curie temperature was 200 °C.

The results thus obtained are shown in Fig. 5.

Comparative Example

Thin layers were formed on a polycarbonate substrate by the same film-forming machine and method as in Example 1 to obtain a magneto-optical recording medium, which was evaluated under the same conditions as in Example 1.

A SiN layer as an interference layer was formed in thickness of 850 Å; a GdFeCo layer as a reproduction layer was formed in thickness of 400 Å; a TbFeCo layer as a recording layer was formed in thickness of 400 Å; and a SiN layer as a protective layer was formed in thickness of 700 Å in the named order to obtain a magneto-optical recording medium of a layered film structure. The composition of the GdFeCo reproduction layer was so set that the compensation temperature was 280 °C and the Curie temperature was at least 350 °C. The composition of the TbFeCo recording layer was so set that the layer was TM-rich at room temperature, and the Curie temperature was 200 °C.

The results thus obtained are shown in Fig. 5.

Using the magneto-optical recording medium and the method for reproducing information recorded in the medium according to the present invention, magnetic domains smaller than a beam spot diameter can

be reproduced as enlarged by means of a simple apparatus without an initialization magnet (conventional apparatus), which enables to achieve high-density recording further improved in the linear recording density and the track density so as to improve the C/N ratio.

Claims

1. A magneto-optical recording medium comprising:
a first magnetic layer which is a horizontal magnetization layer at a room temperature but a perpendicular magnetization layer at a raised temperature, and a transition temperature of which continuously or stepwise increases from an incidence side of light in a film thickness direction; and
a second magnetic layer which is a perpendicular magnetization layer both at the room temperature and at the raised temperature.
2. A magneto-optical recording medium according to Claim 1, wherein said first magnetic layer and said second magnetic layer each are made of a rare earth-transition metal amorphous alloy.
3. An information reproduction method for reproducing information by irradiating an optical beam onto a magneto-optical recording medium, comprising steps of:
irradiating an optical beam onto a magneto-optical recording medium which comprises a first magnetic layer which is a horizontal magnetization layer at a room temperature but a perpendicular magnetization layer at a raised temperature, and a transition temperature of which continuously or stepwise increases from an incidence side of light in a film thickness direction, and a second magnetic layer which is a perpendicular magnetization layer both at the room temperature and at the raised temperature, and in which information is recorded by directions of magnetization, transferring the information recorded in said second magnetic layer to said first magnetic layer, and reading said information by the magneto-optical effect.
4. A magneto-optical recording medium comprising:
a first magnetic layer which has a preferred direction of magnetization in the plane of the layer at a first temperature, and a preferred direction of magnetization perpendicular to the layer above a transition temperature greater than the first temperature, wherein the transition temperature varies in the direction of the thickness of the layer; and
a second magnetic layer which has a pre-

ferred direction of magnetization perpendicular to the layer at least between said first temperature and the highest of said transition temperatures.

5. A magneto-optical recording medium wherein said first magnetic layer comprises a plurality of laminated sub-layers each having a different transition temperature. 5
6. A magneto-optical recording and/or reproducing method comprising: 10
 - directing a beam of radiation onto a magneto-optical recording medium comprising:
 - a first magnetic layer which has a preferred direction of magnetization in the plane of the layer at a first temperature, and a preferred direction of magnetization perpendicular to the layer above a transition temperature greater than the first temperature, wherein the transition temperature varies in the direction of the thickness of the layer, and 15
 - a second magnetic layer which has a preferred direction of magnetization perpendicular to the layer at least between said first temperature and the highest of said transition temperatures, said beam being incident on the surface of the first magnetic layer having the lowest transition temperature. 20
7. A magneto-optical recording and/or reproducing apparatus for performing the method of claim 6. 25

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FIG. 1A

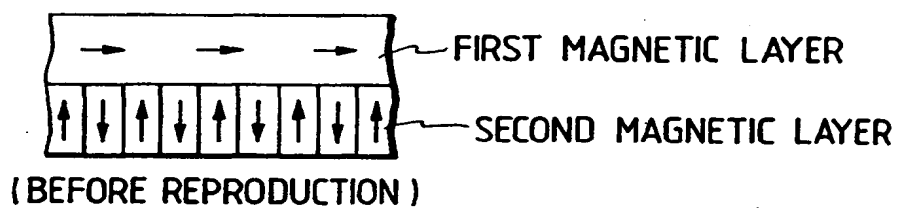


FIG. 1B

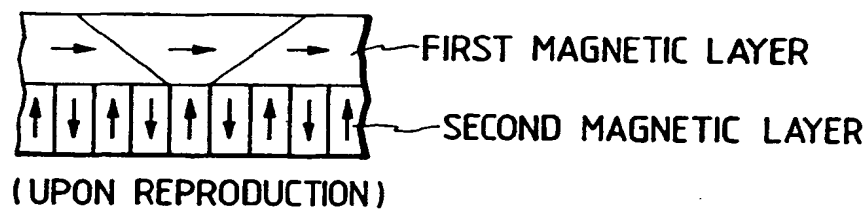


FIG. 2

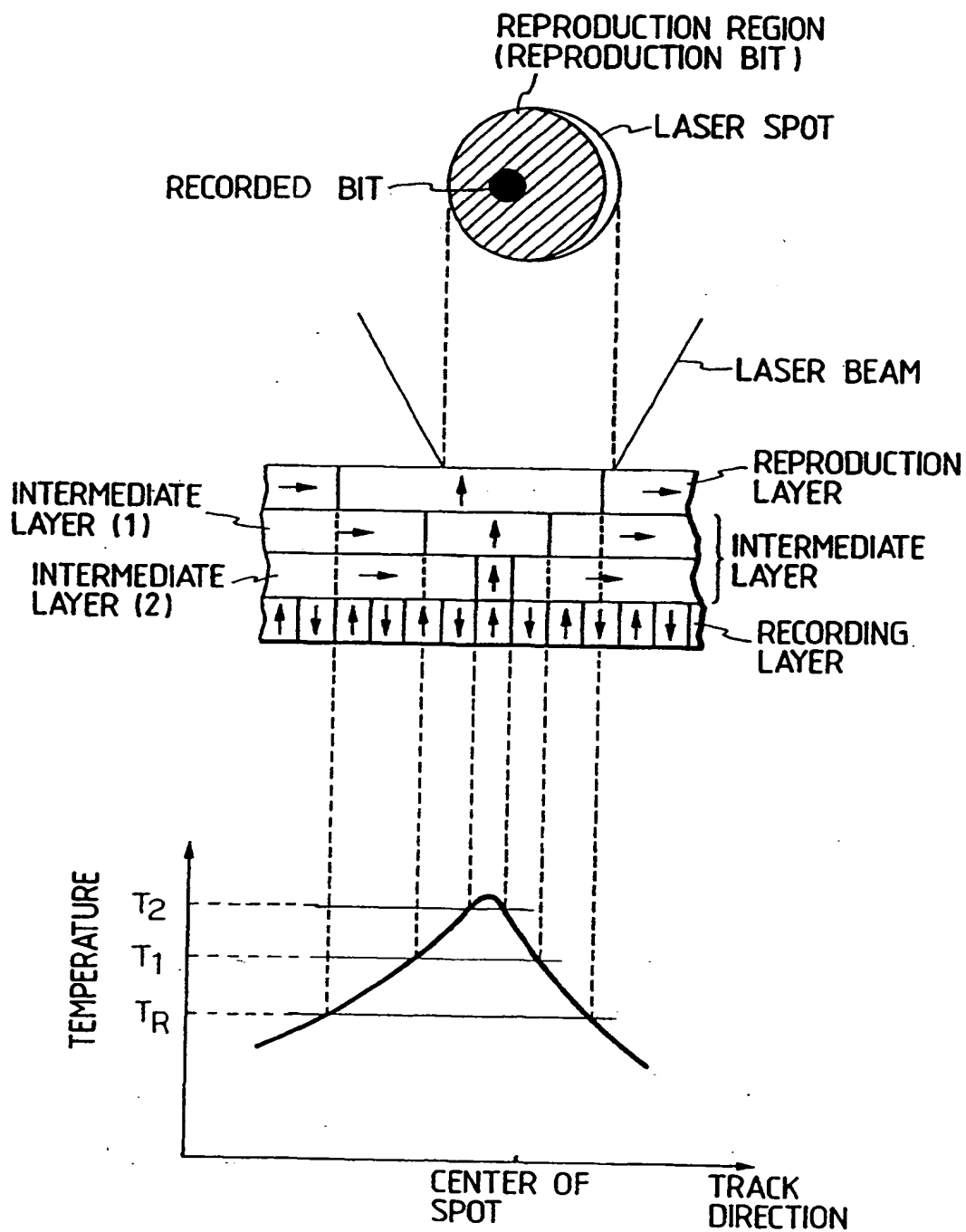


FIG. 3A

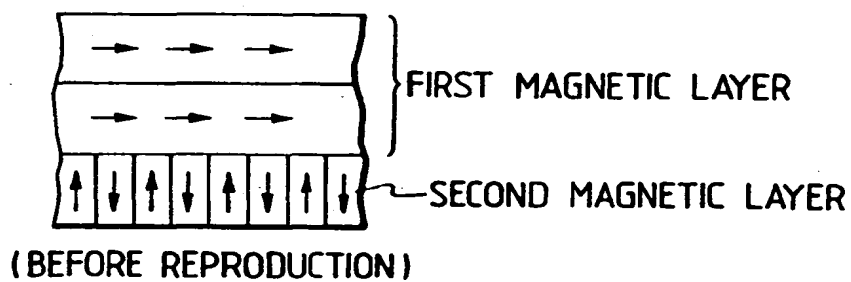


FIG. 3B

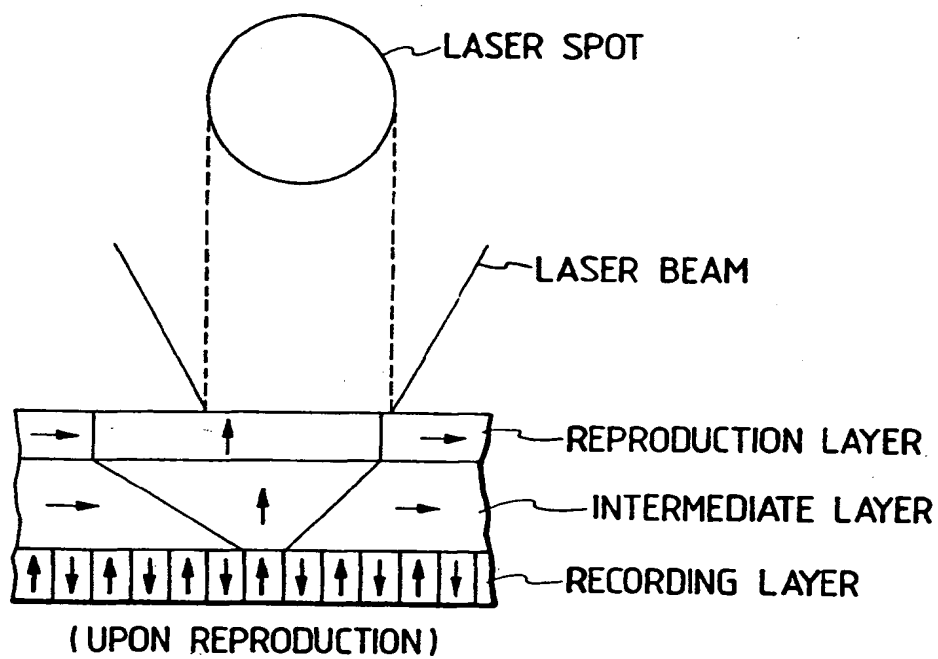


FIG. 4A

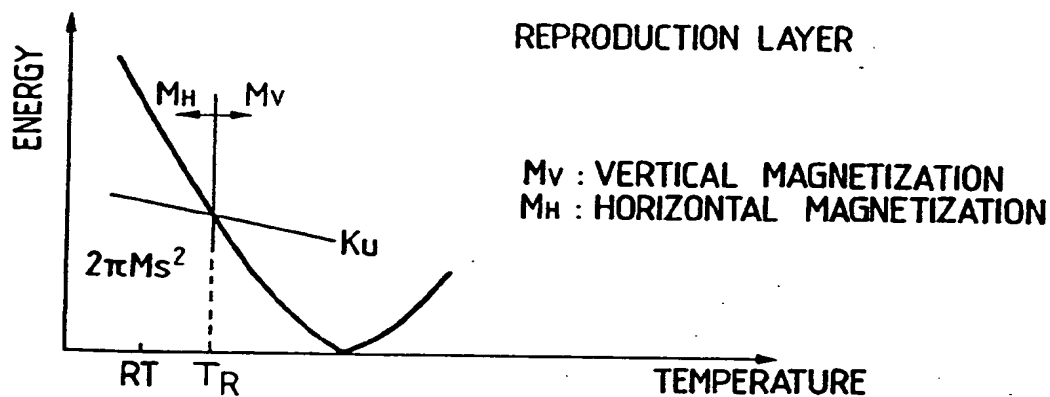


FIG. 4B

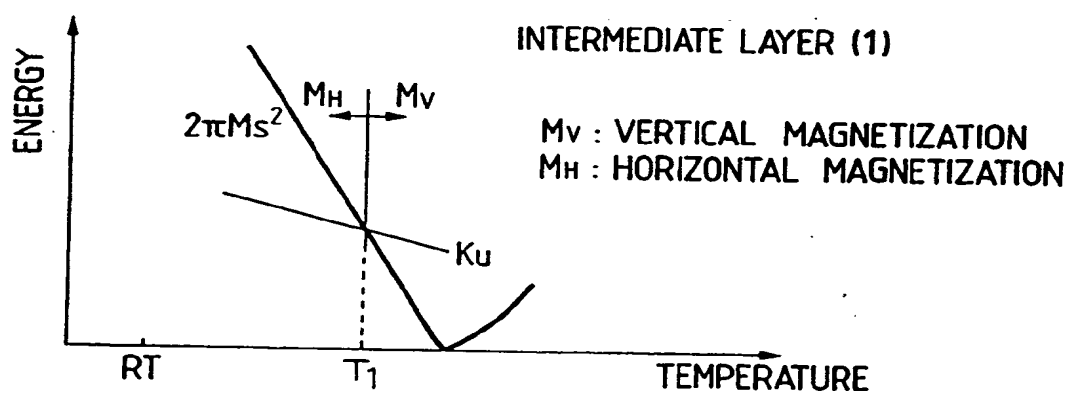


FIG. 4C

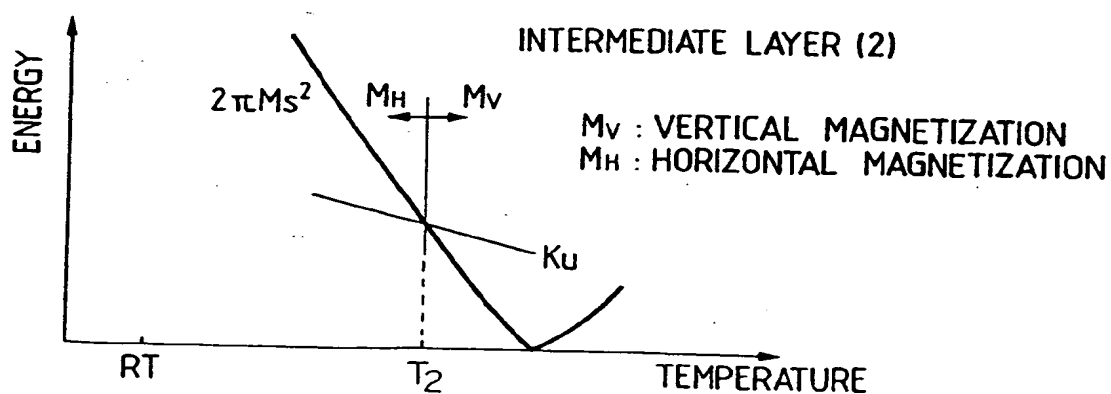


FIG. 5

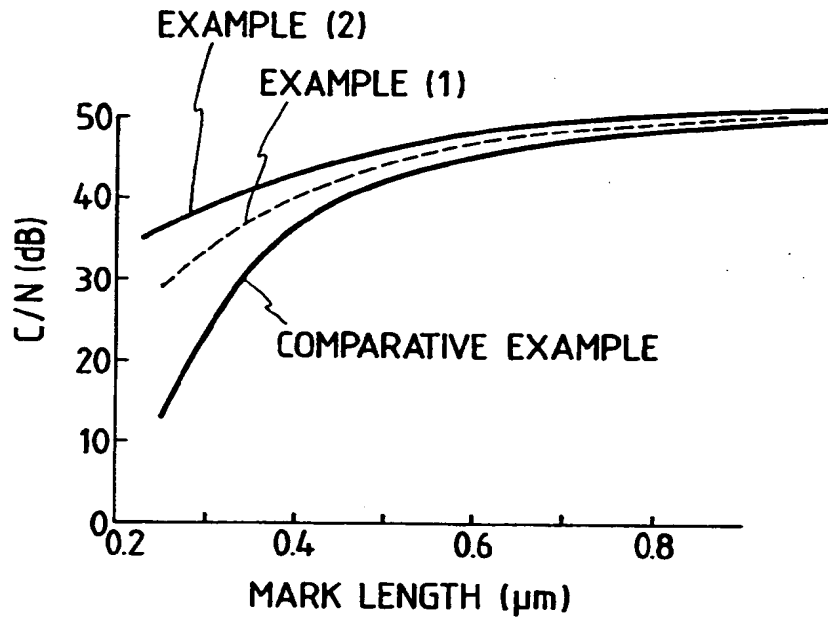


FIG. 6A

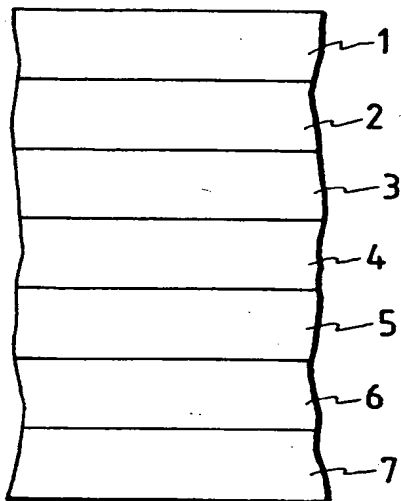


FIG. 6B

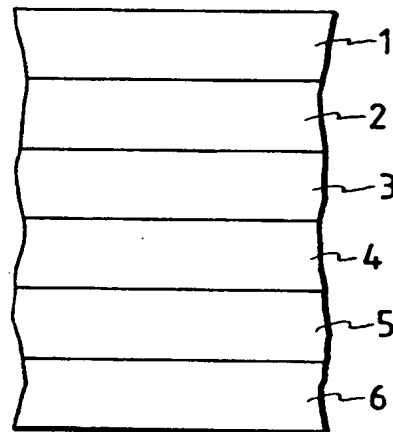
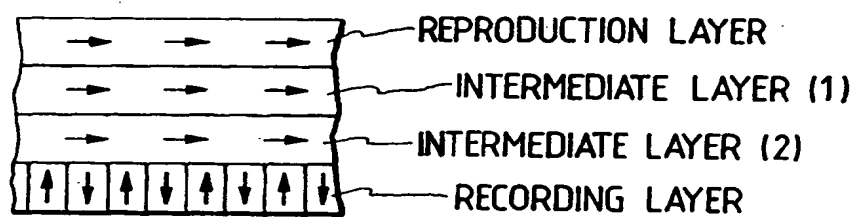


FIG. 7





European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 94 30 2462

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
A	EP-A-0 509 836 (SHARP KK) * claims 1,2,27; figures 1,3 *	1-4,6	G11B11/10
D,A	PATENT ABSTRACTS OF JAPAN vol. 15, no. 274 (P-1226) 11 July 1991 & JP-A-03 093 058 (SONY CORP.) 18 April 1991 * abstract *	1	
			TECHNICAL FIELDS SEARCHED (Int.Cl.5)
			G11B
The present search report has been drawn up for all claims			
Place of search BERLIN		Date of completion of the search 29 June 1994	Examiner Bernas, Y
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